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MACHINE ANALYSIS OF INFRARED CLOUD IMAGES OBTAINED BY THE "COSMOS-122" SATELLITE

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ABSTRACT. A visual analysis of infrared (IR) cloud images, obtained by satellites, is a rather time-consuming operation, and the results are to a large extent subjective. In view of this, it is of interest to automate this analysis by performing it on an electronic computer. The automation problem of the analysis of IR cloud images can be resolved step-by-step. Above all, it is necessary to select the data, defining the IR mimages, from the total information volume, received from the satellite, and encode them into the computer's memory. One of the important methods of solving this problem with respect to satellite-generated IR cloud images is described; a block-diagram of an algorithm for an appropriate program is included. /59*

Subsequent operations of machine processing essentially amounts to identification of the nature of the clouds shown on the photographs. To this end, one of the algorithms stimpulated in the theory of image discrimination is used — the so-called method of potential functions, In this paper we briefly describe the selection of decoding characteristics, used in the machine identification of clouds, and show a block diagram for the computation of these characteristics, as applicable to the IR photographs, taken by the "Cosmos-122" satellite.

The last part of the automated program, described in this study, includes a decision block regarding the type of clouds shown on the analyzed IR photographs. Decision is accomplished by using previously computed magnitudes of the decoding characteristics. This portion of the program can be used in two modes. In the teaching mode, the program, according to the instructions of the operator, who is familiar with the true nature of the clouds on the analyzed photograph, plots a special sequence of numbers, i.e, the "weights" of the decoding characteristics. In accordance with these weights,

* Numbers in the margin indicate the pagination in the original foreign text.

the computer, operating in the recognition mode (which is the working mode) decides on the nature of the clouds, using other IR images, that are not known to the operator.
5 Illustrations; 4 References.

INTRODUCTION

One of the difficult problems in the processing of satellite information is the charting of clouds. At the present time this problem is resolved by visual decoding of television and IR cloud images. The theory and the methods of visual decoding of photographs are fairly well developed. The deficiencies of this method are also well known. Above all, they include the subjectivity and the large time consumption, involved in visual decoding. As a consequence, the information quality depends largely on the experience of the meteorologist-decoder who does the actual decoding of the photographs. /60

A complete elimination of these deficiencies is only possible with automation of television and IR image decoding. Notably, automatic decoding is an extremly complex problem. First of all, there is no comprehensive theory of recognizing objects that are surrounded by a multitude of other objects. We usually encounter this problem in the automation of image decoding when it becomes necessary to separate cloud images from terrestrial surface images, and then to determine the type and the quantity of clouds. Secondly, tremendous difficulties arise when television and IR information is introduced into the automatic processing device, mainly due to the enormous volume of this information (of the order of 10^8 — 10^9 binary units per one satellite orbit for television information, and 10^5 — 10^6 binary units for IR information). Thirdly, there are still no firmly established criteria that qualify the properties of a cloud cover, which require recognition during the analysis of the photographs.

Taking into account these difficulties, the automatic decoding of satellite cloud pictures must be resolved stage by stage, using electronic computers. In automatic image processing, it is possible to subsequently improve and modify the algorithms and the processing programs, which is rather diffitult when specialized devices are used. The input and the distribution of the initial information in the computer's memory is the most complex problem, because, as we mentioned before, the information input is extremely large. Another deficiency of the electronic computer is that it processes the information consecutively, whereas analog devices can be designed so as to give parallel /61 processing of the initial data. However, at the first stage of designing an automatic decoding system, these two deficiencies of an electronic computer can be considered secondary, especially if we limit ourselves to the processing of IR images only.

PROBLEM FORMULATION

The distribution elements of IR photographs obtained by the "Cosmos-122" satellite are such that most of them simultaneously show the clouds, as well as the surface of the Earth. In this instance, the IR signal intensity from the distribution element will be proportional to the mean thermal cloud radiation and the Earth's surface radiation, whose images are available per element. As demonstrated in [2], the distribution law of the radiation temperature for uniform cloud areas (cloud fields) and for the surface of the Earth is unimodal. The statistical parameters of this distribution law (the mathematical expectation and the dispersion of the radiation temperature) depend primarily on the total quantity of clouds. Hence, for areas where there is a strong change of the nature of the cloud cover, the aforenamed distribution law must be bimodal. This property was established previously with respect to the cloud brightness as a result of a photometric analysis of cloud photographs obtained during flights of the spacecraft "Voskhod" and "Voskhod-2" [3, 4].

ALGORITHM OF AUTOMATIC CLOUD DECODING USING IR PHOTOGRAPHS TAKEN BY THE "COSMOS-122" SATELLITE

A block-diagram of the automatic decoding program is shown on Figure 1. It consists of three essential parts: the input block, the computation block of the statistical characteristics of the radiation temperature field, and the recognition block. The operation of the input block of IR information in an electronic computer consists of the following:

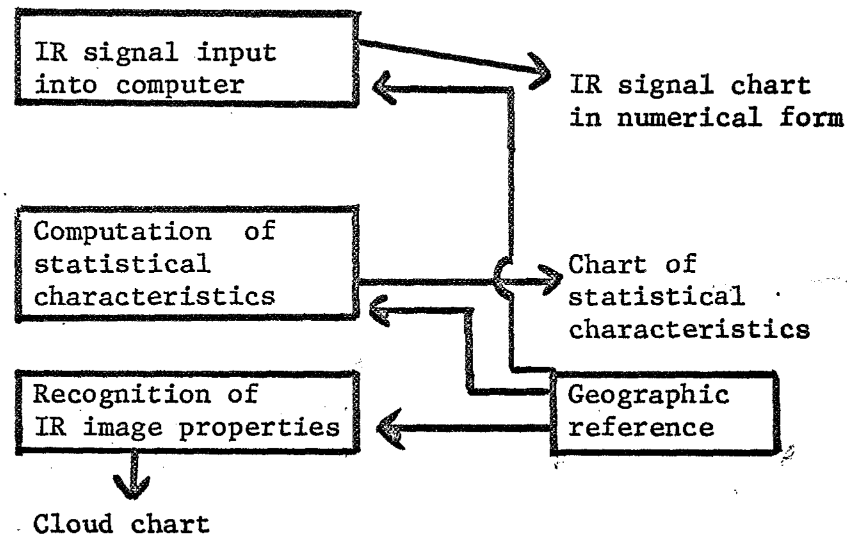

Figure 1. Block-diagram of the automatic decoding program of IR information

The IR of the "Cosmos-122" satellite includes a scanning radiometer; the radiometer readings are received by the ground station in the form of a sequence of codes, along with the data from other scientific and service (or telemetric) satellite equipment. Hence, from the total information flow it is necessary to separate the readings of the IR radiometer only, and then reduce the readings to the specific geometric time structure which was applicable during the satellite survey. /62

The first portion of the problem can be solved if the commutation system of the transducers is known, i.e., the time sequence of the connection of the instruments to the on-board memory device.

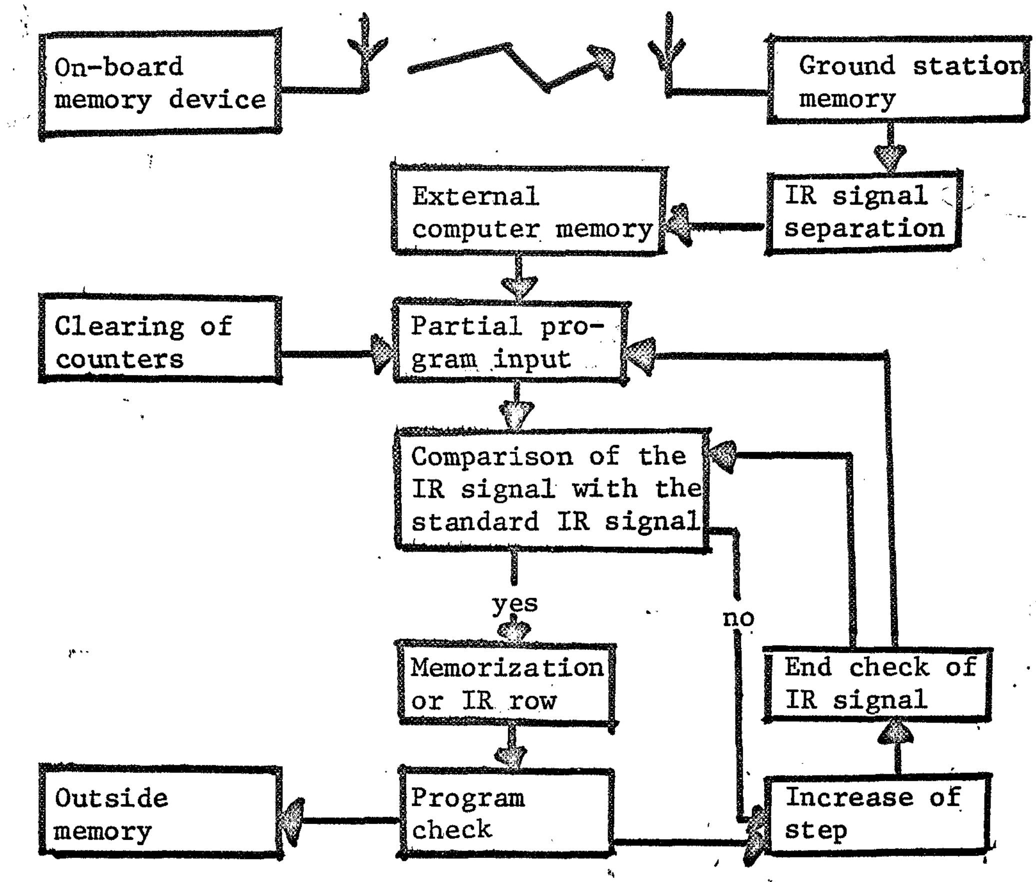

Figure 2. Algorithm block-diagram of IR information input into the electronic computer.

The second part of the problem, i.e., selection of the scanning rows, can be resolved only if the codes that correspond to the IR measurements have some distinguishing characteristics which would enable a comparison of the information with the standard specimen. For purposes of IR measurements, the standard specimen is constructed from a series of artificially introduced signals of a certain amplitude; in conjunction with the specific characteristics of the IR signal, these signals permit a unique determination of the beginning and of the end of the scanning rows.

Thus, the input algorithm of IR information into the computer, as shown in Figure 2, amounts to a sequence of codes. After this sequence is distributed among the on-board transducers and encoded in the computer's external memory, it is transmitted by the individual parts into the operative memory of the machine, where it is compared to the standard.

If there is a coincidence, a scanning row is selected: at the same time, the position of the given row in the overall IR information volume is defined. This in turn, allows us to accomplish a time reference of the rows. If there is /63 no coincidence between the information introduced into the operative memory and the standard reference, the step is increased, and the following group of measurements is compared to the standard. As the operative computer memory is filled up by the selected rows, these rows are transferred to the external memory of the machine. This process is repeated, until all of the initial data are processed.

A sequence of numbers, obtained from the output of the input block, is fed into the input of the computation block of statistical characteristics of the radiation temperature. The numbers are received in element after element and row after row; in sequence. From a structural view point, the block consists of two second-level blocks; of these, the first one is designed to compute the mean radiation temperature values, its dispersion, asymmetry and excess. This computation is performed for IR images with an area of 35 x 35 distribution elements.

To reduce the calculation volume, we selected the radiation temperature values in 324 distribution elements, located at equal distances from each other (18 x 18 elements). The loss of the calculation accuracy of the statistical characteristics of the radiation temperature is rather insignificant, inasmuch as the IR signal values are strongly correlated for adjacent distribution elements. On the other hand, this operation reduces the IR data volume by the factor of four.

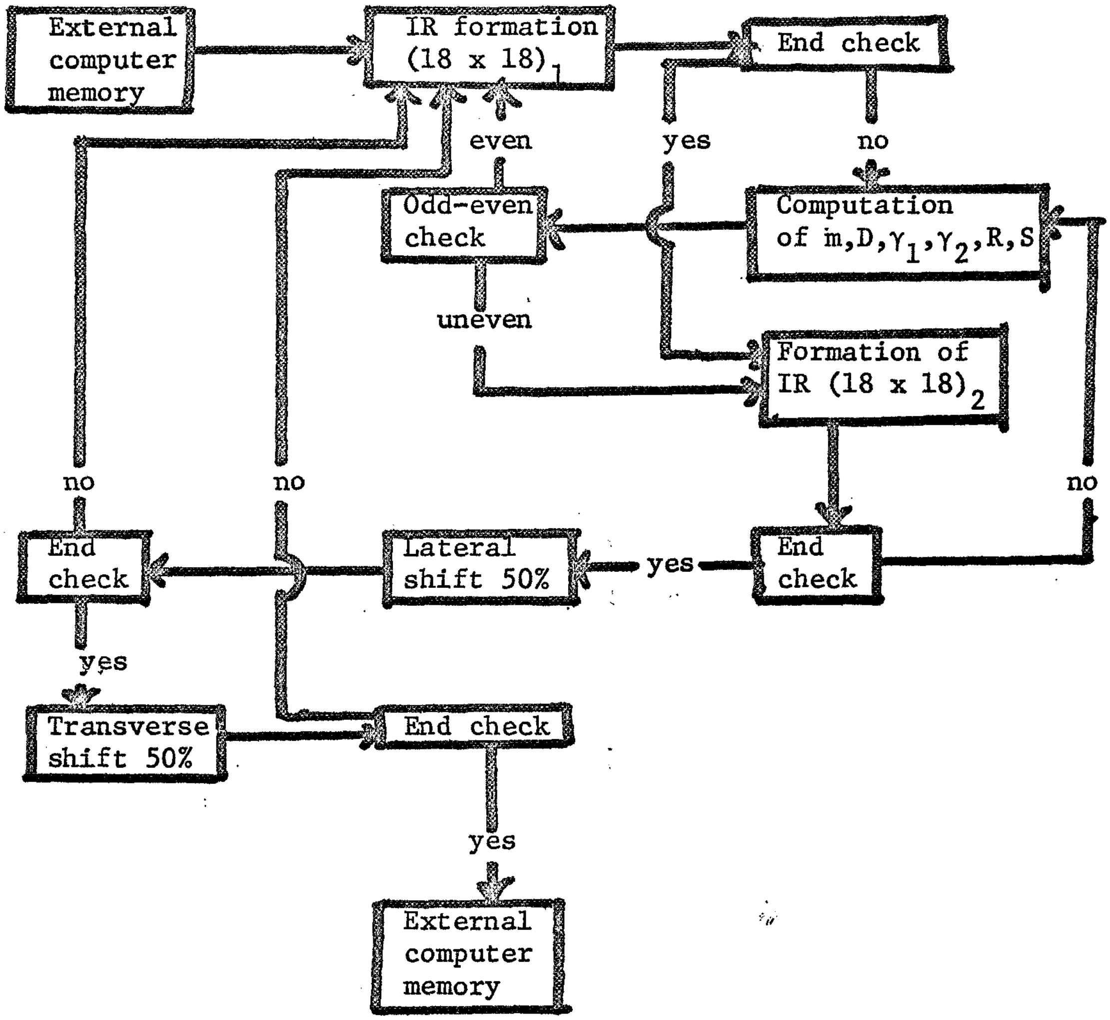

Figure 3. Algorithm block-diagram for the computation of the statistical characteristics.

Areas of 35 x 35 elements are formed with a 50% overlap, along as well as across the scanning rows of the on-board IR radiometer. Thus, along the diameter of the IR survey band, we have a total of six areas for each of which the statistical characteristics are being computed.

The second block is designed for the calculation of the bivariate correlation function and of the bivariate spectrum of the radiation temperature based on the quadratic matrix of n x n distribution elements (where n is a variable, set by the operator). The block does not operate on each of the IR image areas, but selectively, depending on the output of the recognition/discrimination block.

At the output of the block we obtain an ordered sequence of statistical characteristics of the radiation temperature, computed for areas of IR images of regular dimensions . This sequence may be printed out in the form of charts of statistical characteristics of the radiation temperature. However, at the present time, there is only a provision for their output in the form of a numerical sequence, without any geographic reference. The block diagram for the computation of the characteristics is shown on Figure 3.

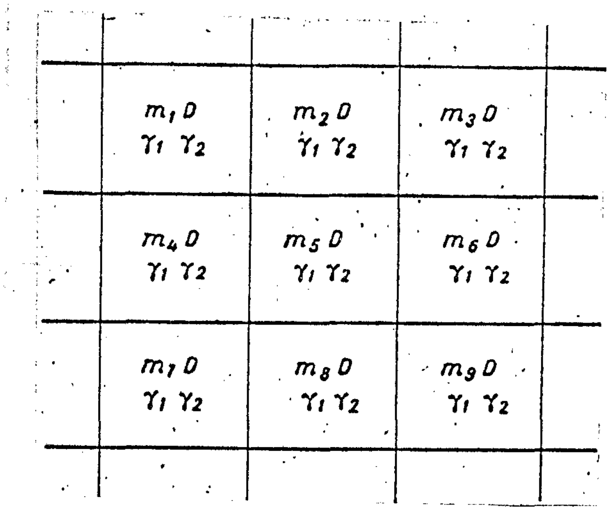

Figure 4. Diagram for the selection of decoding characteristics to identify strong changes in the properties of the cloud cover and of the surface of the Earth.

In the framework of our problem, the recognition unit is the principal component. Structurally speaking, it is one unit; however, the algorithm that is encoded in it is used alternately for two different operations. The first operation is the identification of strong changes in the nature of the cloud cover and of the surface of the Earth. To this end, we use the values of statistical characteristics, of the radiation temperature, (mathematical expectation, dispersion, assymmetry and excess). Since, it is assumed that a strong variation of the nature of the cloudiness or of the surface of the Earth may be discovered from the relative variations of the values of the aforenamed characteristics, the statistical characteristics values for nine adjacent IR image areas are used as decoding characteristics of the program (Figure 4).

Since each area is defined by four statistical parameters, the total number of criteria is 36. All these 36 criteria are used to identify the presence or the absence of strong variations of the nature of the cloud cover, i.e., finding on the IR photograph the boundaries of the cloud field or the surface of the Earth in the central area (Figure 4).

The algorithm (Figure 5) is based on the so-called method of potential functions [1]. Following is the essence of this method. /65

The total information complex available to us for solving the problem of identifying the boundary position of cloud fields on the IR photograph is contained in a certain (usually not very large) number of IR photographs; for each one of these photographs, the cloud field boundaries are given. Moreover, we have a listing of the quantitatively-measureable properties of the IR image, which include a considerable share of the information on the position of subject boundaries.

It is possible to construct a multivariate space, with the informative properties (decoding characteristics) of the IR image used as axes of this space, these properties or characteristics being expressed numerically. In such a space, each IR image will be represented by a point with coordinates which correspond to those values of the decoding characteristics that are applicable to the given IR image. In this particular space we must determine a metric. Then the points, which have IR images that are comparable in their properties, will be located in a multivariate space of characteristics, relatively close to each other. On the other hand, points of strongly different IR images will be allocated at large distances. In short, in the characteristic space, we can construct hypersurfaces in such a manner that we can separate the points relating to IR images with substantively different properties.

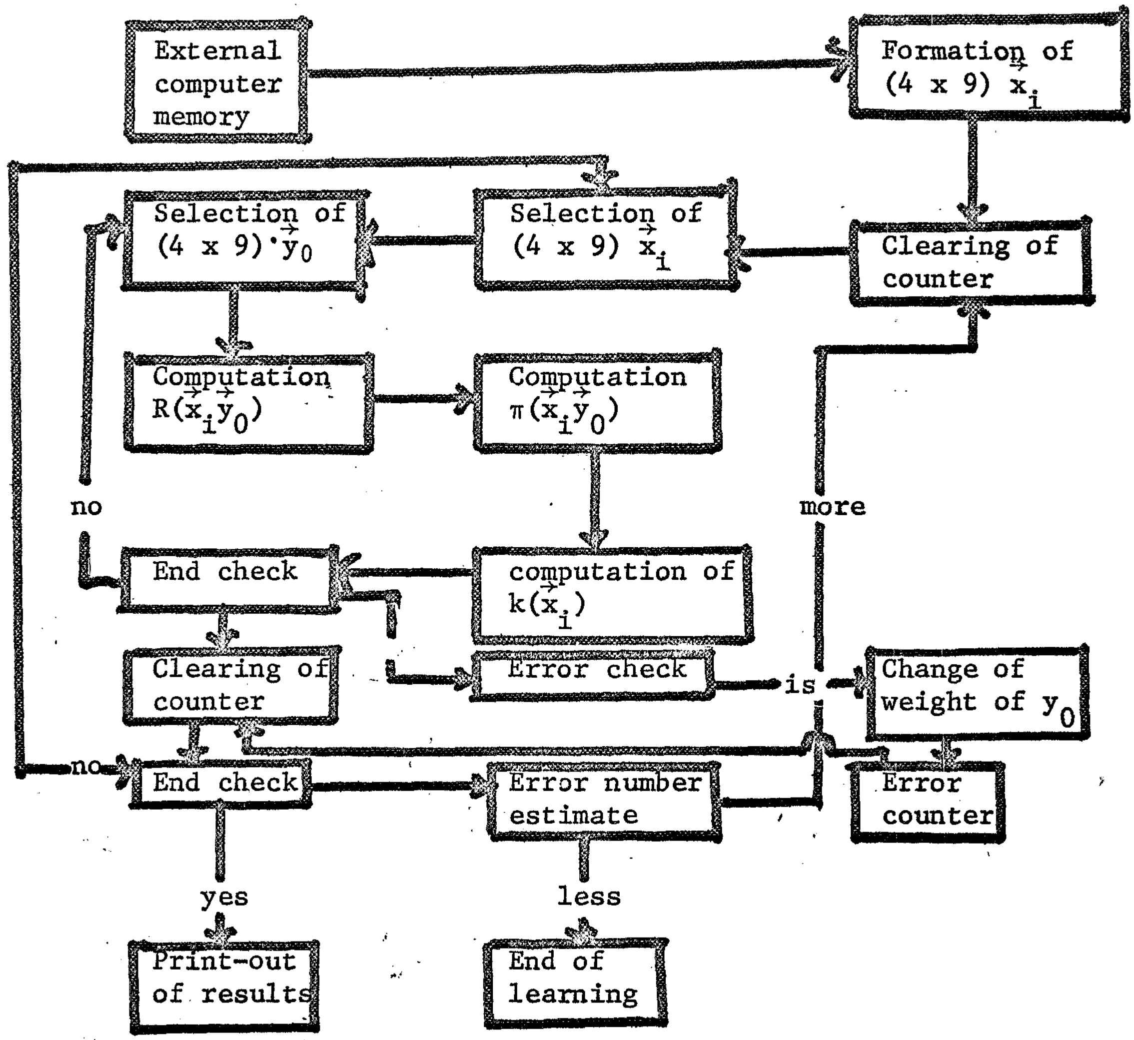

Figure 5. Block-diagram of the identification algorithm

The algorithm of potential functions makes it possible to plot separating hyperplanes, using a relatively small number of points (IR photographs) which are known to form an image. To this end, into the space of characteris- /66 tics,we introduce a so-called potential function, which must satisfy the following conditions: it must be limited over the entire space of characteristics and be sufficiently smooth, i.e., have no jumps and no discontinuities. The function

$$\Pi(\vec{x}, \vec{y}) = \frac{1}{1+\alpha R^2}, \qquad (1)$$

satisfies these conditions; here $R = \|\vec{x} - \vec{y}\|$ is the distance in the characteristic space between points with coordinates $\vec{x}$ and $\vec{y}$.

The identification algorithm, based upon the method of potential functions, consists of two parts: learning and identification proper. During the learning process, we introduce into the operative memory of the computer codes of numbers which define the properties of the decoding characteristics of IR images with known properties. As we mentioned, the code of decoding characteristics in our program has 36 numerals. We can simultaneously introduce about 100 such codes into the operative memory of the machine. For each of these codes, there is an indication as to what type of IR image is described by this particular code.

At the identification proper stage, new and unknown IR images will be identified, using the aforenamed codes with a sign (codes of known images). The identification consists of the determination of the sign of the function.

$$K(\vec{x}^*) = \sum_{l=1}^{n} \gamma_l \Pi (\vec{x}^* \vec{y}_l), \tag{2}$$

where $\vec{x}^*$ is a point in a space of characteristics, corresponding to the image that is being identified; $\vec{y}_i$ are points ($i = 1, \ldots, n$), corresponding to codes with a sign that is stored in the operative memory of the computer; γ_i are the "weights" of the codes with a sign.

The "weights" are selected so as to provide for a correct (or with a given accuracy) identification of the IR images. To this end, during the teaching process we alternately introduce into the operative memory of the computer codes of the same IR images, which have been previously introduced into the machine, with their signs. The computer performs the calculations, using Formula (2) for each of the newly introduced codes; thereupon, the sign of function $K(\vec{x}^*)$ is compared to the true sign of the code, which is being identified at the given moment. If the signs coincide, it follows that the computer made a correct recognition of the given IR image. Then the computation is performed using Formula (2) for the subsequent code from the number of codes with a sign, etc. However, if the true sign of the code and the sign, derived from Formula (2), do not coincide, then the weight γ_i of the analyzed IR image is changed, using Formula (3)

$$\gamma_i(j+1) = \gamma_i(j) + 1. \tag{3}$$

In subsequent tests concerning the validity of recognition of new codes, from a number of codes with a sign, the changed weight of the code is taken into account.

With a multiple repetition of the tests, the number of errors is gradually reduced to zero, provided that the recognized IR images actually have different properties. When this stage is attained, the teaching is discontinued, and the program becomes usable for recognition of new, previously unknown IR images.

As we mentioned before, at the beginning of this study, the statistical calculation unit of our program puts out 6 x 150 = 900 values of mathematical expectation, dispersion, asymmetry and excess of IR signals for each operational cycle of the on-board IR equipment of the "Cosmos-122" satellite in the half-orbit in the shade. From these values, the recognition unit forms 500 codes, which are subject to recognition, using the aforenamed program (4 codes over the bandwidth of the IR photo, and about 130 codes along it). The recognition results are put out in the form of charts of cloud field boundaries; for this, a geographic reference of the codes for which the cloud field boundary during the recognition was indicated must be made. Theoretically, the geographic reference program does not differ from the program that is used for the geographic reference of the actinometric information of the "Cosmos-122" satellite.

There is one circumstance, however, that should be kept in mind, when using IR images, recognized by a computer with reference to the aforenamed program. A drastic change in the properties of the IR image takes place not just when tracing the boundaries of cloud fields, but also in the survey of the boundaries of continents and landscape areas. Our program does not have the capability of separating these cases. However, this is of no substantial importance.

Such a separation is easily performed during the geographic referencing of the recognition results and during subsequent recognition of the cloud type, within the limits of each delineated contour. If, after geographic referencing, the recognition boundary is sufficiently far from the continental boundaries, etc., then it can be construed as the boundary of cloud fields. Otherwise, it may reflect the variation of the properties of the surface of the Earth.

In conclusion, it should be pointed out that the aforenamed program contains units which will permit future recognition of the type of clouds within the confines of each separated cloud field, using the method of consecutive bifurcation. For decoding purposes, it is conceivable to use the same statistical characteristics which are used in boundary recognition of conventional cloud fields, in addition to bivariate correlation functions and the bivariate spectrum of the IR signal.

In addition, it will become necessary to introduce into the computer memory the data on thermal radiation for various areas of the globe in cloudless weather. The absence of such standards precluded us from performing an experiment on cloud recognition in the framework of this program. Insofar as other elements of this program are concerned, they were tested on actual IR data obtained from the "Cosmos-122" satellite.

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